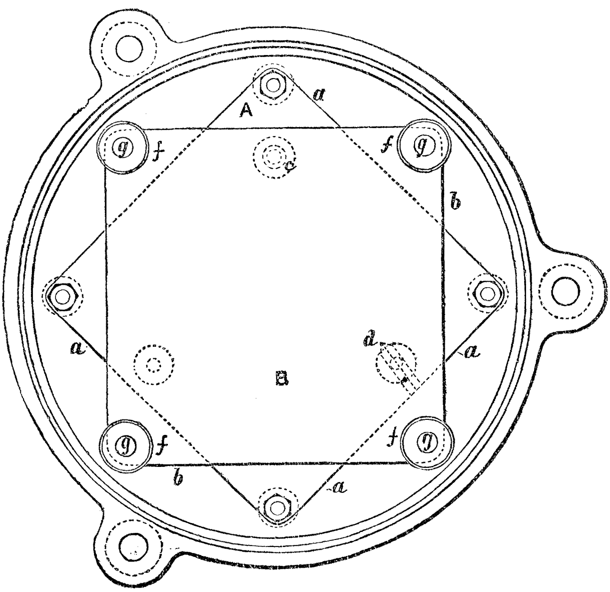
IV. "On a new Form of Air Leyden, with Application to the Measurement of Small Electrostatic Capacities." By LORD KELVIN, P.R.S. Received May 31, 1892.

In the title of this paper as originally offered for communication "*Air Condenser*" stood in place of "*Air Leyden*," but it was accompanied by a request to the Secretaries to help me to a better designation than "Air Condenser" (with its ambiguous suggestion of an apparatus for condensing air), and I was happily answered by Lord Rayleigh with a proposal to use the word "leyden" to denote a generalised Leyden jar, which I have gladly adopted.

The apparatus to be described affords, in conjunction with a suitable electrometer, a convenient means of quickly measuring small electrostatic capacities, such as those of short lengths of cable.

The instrument is formed by two mutually insulated metallic pieces, which we shall call A and B, constituting the two systems of an air condenser, or, as we shall now call it, an air leyden. The systems are composed of parallel plates, each set bound together by four long metal bolts. The two extreme plates of set A are circles of much thicker metal than the rest, which are all squares of thin

FIG. 1.



sheet brass. The set B are all squares, the bottom one of which is of much thicker metal than the others, and the plates of this system are one less in number than the plates of system A. The four bolts binding together the plates of each system pass through well-fitted holes in the corners of the squares; and the distance from plate to plate of the same set is regulated by annular distance pieces which are carefully made to fit the bolt, and are made exactly the same in all respects. Each system is bound firmly together by screwing home nuts on the ends of the bolts, and thus the parallelism and rigidity of the entire set is secured.

The two systems are made up together, so that every plate of B is between two plates of A, and every plate of A, except the two end ones, which only present one face to those of the opposite set, is between two plates of B. When the instrument is set up for use, the system B rests by means of the well-known "hole, slot, and plane arrangement,"* engraved on the under side of its bottom plate, on three upwardly projecting glass columns which are attached to three metal screws working through the sole plate of system A. These screws can be raised or lowered at pleasure, and by means of a gauge the plates of system B can be adjusted to exactly midway between, and parallel to, the plates of system A. The complete leyden stands upon three vulcanite feet attached to the lower side of the sole plate of system A.

In order that the instrument may not be injured in carriage, an arrangement, described as follows, is provided by which system B can be lifted from off the three glass columns and firmly clamped to the top and bottom plates of system A.

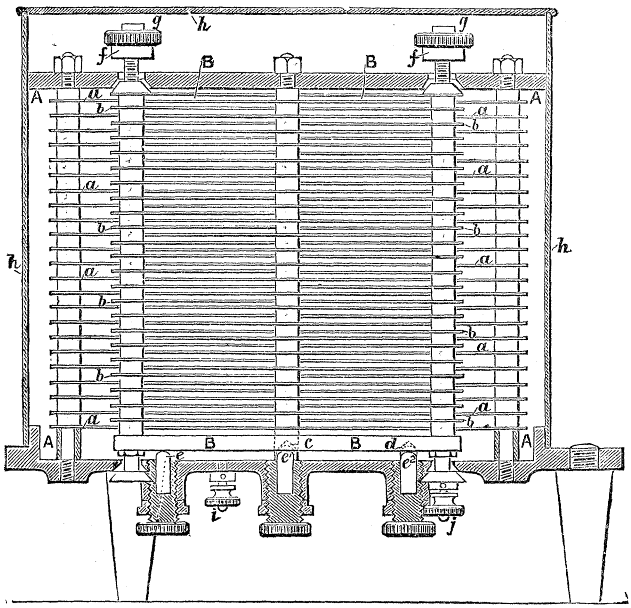
The bolts fixing the corners of the plates of system B are made long enough to pass through wide conical holes cut in the top and bottom plates of system A, and the nuts at the top end of the bolts are also conical in form, while conical nuts are also fixed to their lower ends below the base plate of system A. Thumbscrew nuts, *f*, are placed upon the upper ends of the bolts after they pass through the holes in the top plate of system A.

When the instrument is set up ready for use these thumbscrews are turned up against fixed stops, *g*, so as to be well clear of the top plate of system A.; but when the instrument is packed for carriage they are screwed down against the plate until the conical nuts mentioned above are drawn up into the conical holes in the top and bottom plates of system A; system B is thus raised off the glass pillars, and the two systems are securely locked together so as to prevent damage to the instrument.

A dust-tight cylindrical metal case, *h*, which can be easily taken off for inspection, covers the two systems and fits on to a flange on

* Thomson and Tait's 'Natural Philosophy,' § 198, example 3.

Fig. 2.



system A. The whole instrument, as said above, rests on three vulcanite legs attached to the base plate of system A; and two terminals are provided, one, *i*, on the base of system A, and the other, *j*, on the end of one of the corner bolts of system B.

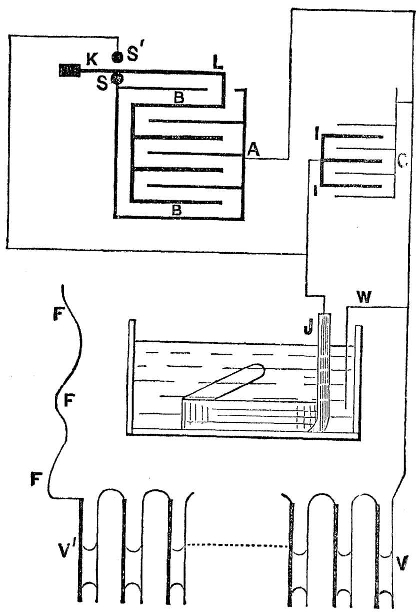
The air leyden which has been thus described is used as a standard of electrostatic capacity. In the instrument actually exhibited to the Society there are twenty-two plates of the system B, twenty-three of the system A, and therefore forty-four octagonal air spaces between the two sets of plates. The thickness of each of these air spaces is approximately 0·301 of a centimetre. The side of each square is 10·13 cm., and therefore the area of each octagonal air space is 85·1 sq. cm. The capacity of the whole leyden is therefore approximately $44 \times 85{\cdot}1/(4\pi \times 0{\cdot}301)$, or 990 cm. in electrostatic measure; or $1{\cdot}1 \times 10^{-18}$ c.g.s., electromagnetic measure; or $1{\cdot}1 \times 10^{-9}$ farads, or $1{\cdot}1 \times 10^{-3}$ microfarads. This is only an approximate estimate founded on a not minutely accurate measurement of dimensions, and not corrected for the addition of capacity, due to the edges and projecting angles of the squares and the metal cover. I hope to have the capacity determined with great accuracy by comparison with Mr. Glazebrook's standards in Cambridge.

To explain its use in connexion with an idiostatic electrometer for the direct measurement of the capacity of any insulated conductor, I shall suppose, for example, this insulated conductor to be the

insulated wire of a short length of submarine cable core, or of telephone, or telegraph, or electric light cable, sunk under water, except a projecting portion to allow external connexion to be made with the insulated wire.

The electrometer which I find most convenient is my "multicellular voltmeter," rendered practically dead-beat by a disc under oil hung on the lower end of the long stem carrying the electric "needles" (or movable plates). In the multicellular voltmeter used in the experimental illustration before the Royal Society, the index shows its readings on a vertical cylindric surface, which for electric light stations is more convenient than the horizontal scale of the multicellular voltmeters hitherto in use; but for the measurement of electrostatic capacity the older horizontal scale instrument is as convenient as the new form.

FIG. 3.



To give a convenient primary electrification for the measurement, a voltaic battery, VV′ (fig. 3), of about 150 or 200 elements, of each of which the liquid is a drop of water held up by capillary attraction between a zinc and copper plate about 1 mm. asunder. An ordinary electric machine, or even a stick of rubbed sealing-wax may, however, be used, but not with the same facility for giving the amount of electrification desired as the voltaic battery.

One end of the voltaic battery is kept joined metallically to a wire,

W, dipping in the water in which the cable is submerged, and with the case C of the multicellular, and with the case and plates A of the leyden, and with a fixed stud, S, forming part of the operating key to be described later. The other end of the voltaic battery is connected to a flexible insulated wire, FFF, used for giving the primary electrification to the insulated wire J of the cable, and the insulated cells II of the multicellular kept metallically connected with J. The insulated plates, B, of the leyden are connected to a spring, KL, of the operating key referred to above, which, when left to itself, presses down on the metal stud S, and which is very perfectly insulated when lifted from contact with S by a finger applied to the insulating handle K. A second well insulated stud, S′, is kept in metallic connection with J and I (the insulated wire of the cable and the insulated cells of the multicellular).

To make a measurement the flexible wire F is brought by hand to touch momentarily on a wire connected with the stud S′, and immediately after that a reading of the electrometer is taken and watched for a minute or two to test either that there is no sensible loss by imperfect insulation of the cable and the insulated cells of the multicellular, or that the loss is not sufficiently rapid to vitiate the measurement. When the operator is satisfied with this he records his reading of the electrometer, presses up the handle K of the key, and so disconnects the plates B of the leyden from S and A, and connects them with S′, J, I. Fifteen or twenty seconds of time suffices to take the thus diminished reading of the multicellular, and the measurement is complete.

The capacity of the cable is then found by the analogy:—As the excess of the first reading of the electrometer above the second is to the second, so is the capacity of the leyden to the capacity of the cable.

The preceding statement describes the arrangement which is most convenient when the capacity of the cable exceeds the capacity of the leyden. The plan which is most convenient in the other case, that is to say, when the capacity of the cable is less than that of the leyden, is had by interchanging B and J throughout the description. In this case, a charge given to the leyden is divided between it and the cable. The capacity of the cable is then found by the analogy:—As the second reading of the electrometer is to the excess of the first above the second, so is the capacity of the leyden to the capacity of the cable.

A small correction is readily made with sufficient accuracy, for the varying capacity of the electrometer, according to the different positions of the movable plates, corresponding to the different readings, by aid of a table of corrections determined by special measurements for capacity of the multicellular.

FIG. 2.